

Fragmentation of Habitat by Roads and Utility Corridors: A Review

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ABSTRACT

This review examines the ecological effects of roads and utility corridors such as powerlines, pipelines, canals and railway lines on undisturbed habitat and native wildlife. Public concern about roads in natural areas is increasing, as shown by the public protests against forest roads in the Central Highlands of Victoria and the National Estate areas in the south-east forests of New South Wales. The Daintree Road through Queensland's tropical rainforest created an international protest and remains Australia's most notorious road. The original Very Fast Train (VFT) proposal favoured a route which would have divided the two major wilderness areas of the Gippsland forests in Victoria by creating a fenced impenetrable barrier to some wildlife. Planning authorities need to address the impacts of fragmentation of natural habitats by such developments.

Although it is difficult to draw conclusions from a comparison of studies covering different countries, species and habitats, areas of concern for wildlife conservation and management emerge, including increased mortality, divided populations and invasions of common species. There is a need for studies on the effects of these linear artifacts on Australian wildlife.

INTRODUCTION

"The arguments in favour of roads are direct and concrete, while those against them are subtle and difficult to express" (Marshall 1935). (Marshall was the first campaigner against the construction of roads in the last undeveloped areas of the United States of America.) Roadsides and utility corridors such as railway lines, pipelines, powerlines and canals are the only relatively undisturbed remnants left to serve as wildlife refuges in many developed areas. They are also important as wildlife corridors to connect natural areas, allowing wildlife movement, although this depends greatly on the width of undisturbed native vegetation on the verges (Grieves and Lloyd 1984; Arnold *et al.* 1987; Bennett 1988; Cale 1990; Bennett, in press; Saunders, in press). The value of roadsides as wildlife corridors will depend on their management, as they are also sources of invasion of weeds and feral predators (Simberloff and Cox 1987; Noss 1987).

The fragmentation of natural areas into small remnants affects wildlife populations by reducing the number of species through limiting their ability to move from one area to another (Burgess and Sharpe 1981; Harris 1984; Wilcox and Murphy 1985; Saunders *et al.* 1987).

In largely natural areas roads and utility corridors subdivide the area into "islands" for some species, and create an edge effect (see Fig. 1). The design of studies examining the effects of roads and utility corridors on wildlife in natural areas is usually species specific. Without these investigations it is easy to assume that the

construction of a road will merely displace the fauna from the area developed.

This review examines studies which have revealed the following harmful effects of roads:

- (1) habitat loss and modification with accompanying effect on populations;
- (2) intrusion of the edge effect into the core of natural areas;
- (3) subdivision and isolation of populations by acting as a barrier;
- (4) a source of disturbance to wildlife;
- (5) increased road-kills;
- (6) increased human access with undesirable impacts on undisturbed areas.

The following definitions are used in this review: roads refer to the area cleared for vehicles, whether dirt or paved; roadsides are the cleared or vegetated verges alongside roads; utility corridors for railway lines, pipelines, powerlines or canals include the construction itself and the area alongside which may be cleared or revegetated. All utility corridors have access roads. The areas may be fenced, and many studies refer to them as corridors or rights-of-way. Roughly bulldozed trails and seismic lines are specified in this review.

HABITAT LOSS AND MODIFICATION

Destruction and Modification of Vegetation

Considerable areas are destroyed or altered by linear constructions. In the United States of America powerline

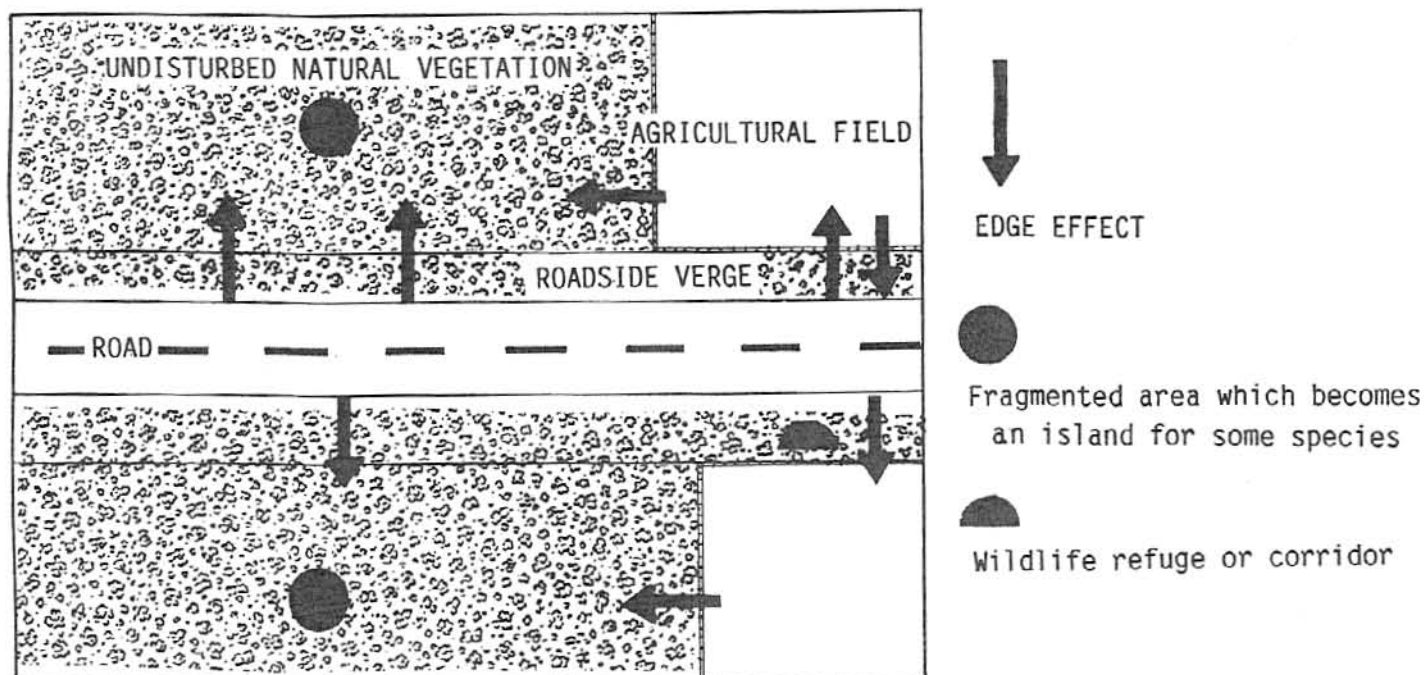


Figure 1. Comparative effects of a road on undisturbed and modified habitats.

right-of-way will cover 3.4 million ha by the year 2000 (Johnson 1979), and for each kilometre of transmission line 25-40 ha of land is compacted (Brum *et al.* 1983). In Australia in 1976 there were 866 000 km of road, and roads in Victoria occupied 2.5% of the State compared with 7.7% dedicated to National Park (Bennett 1990). In Queensland, approximately 20% of the Daintree National Park's lowland tropical rainforest, our rarest rainforest type, lies within the gazetted Daintree Road reserve, and most of this has been bulldozed for the road (Borschmann 1984).

All the constructions involve considerable changes caused by the need to clear, level, cut and fill. Hydrological patterns are altered and cause siltation of waterways. The amount of soil compaction affects the revegetation of the construction area. In Australian arid zones, the cleared grids of seismic lines have led to soil compaction which inhibits revegetation, leading to erosion and siltation of important watercourses (O'Loughlin 1989).

Although vegetation can regrow on utility corridors, it is usually maintained at an earlier successional stage by cutting, mowing or spraying of herbicides. This affects the plants and animals living there. Studies undertaken in the United States have shown that in some habitats, such as deserts, the recovery of vegetation was slow, and revegetation programmes were expensive and could be unsuccessful (Brum *et al.* 1983). In the Sonoran Desert, areas cleared for the powerline corridor and towers

suffered less environmental damage than the access road, and corridor succession of vegetation and insect colonization took place slowly (Johnson *et al.* 1981). In the Mojave Desert, vegetation under a powerline had not completely recovered after 33 years (Vasek, Johnson and Brum 1975), while the recovery for a pipeline corridor, which involved trenching, piling and refilling, was expected to take one to several centuries (Vasek, Johnson and Eslinger 1975).

Wetlands are also sensitive, and in the USA are often used to site powerline corridors. A study of revegetation of three different wetland types over 10 years showed that the shrub/bog wetland had not recovered as well as the other types (Nickerson *et al.* 1989). The study emphasized that vegetation recovery may not necessarily indicate the functional recovery of the wetland, including water quality, groundwater recharge and its use as wildlife habitat.

Alteration of Hydrology and Siltation of Aquatic Habitats

Only major constructions require environmental impact assessments to predict impacts. Even if the recommendations made in an EIS are followed they cannot protect the environment fully. The F3 Freeway in New South Wales was constructed along the edge of Ku-ring-gai Chase National Park with extensive erosion control measures. Unusually heavy rainfall led to the

failure of some sediment traps, leading to sedimentation and smothering of benthic organisms in catchment creeks. Consequently, these sediment traps will need continual maintenance. One unforeseen impact on vegetation was the release of permanent low flows of water from the sub-soil drains into dry sclerophyll woodlands, leading to die-back of vegetation in two locations (Rooney 1989).

Broadbent and Cranwell (1979) reviewed studies on erosion and sedimentation caused by road construction, and found that, in the United States, highway construction in 11% of a catchment area contributed 85% of the sediment leaving the catchment. Roading was seen as the major source of increased sediment loads in catchments from which timber was harvested in studies reviewed by Campbell and Doeg (1989). Reductions in species diversity, reductions in biomass and changes in species composition were the most widely reported changes resulting from stream siltation (Campbell and Doeg 1989).

Impact on Species with Localized Habits

Species most vulnerable to roads and utility corridors are those with poor dispersal abilities, sedentary habitats, specialized needs and those endemic to an area. California's unique vernal pools with their specialized endemic species have suffered through road construction. The rare Santa Cruz long-toed salamander *Ambystoma macrodactylum croceum* is threatened by a highway running through one of the two vernal pools in which it breeds (Robinson 1986). A powerline easement missed by a few metres a small patch of *Bursaria spinosa* bushes on which Australia's rarest butterfly *Paralucia spinifera* exists (Kitching and Baker 1990).

Quantifying Habitat and Wildlife Loss

Kroodsma (1985) reviewed 130 environmental impact statements which identified claims for impacts which included: habitat lost, wildlife lost, carrying capacity reduced, mobile fauna displaced, immobile fauna destroyed. The 17 highway EISs presented the fewest assessments of habitat loss, and did not fully discuss the displacement of fauna. Kroodsma concluded that the extent of habitat loss should be quantified and its ecological importance discussed. Kroodsma felt that the fragmentation of the habitat should also be addressed. He concluded that each species will decline at least in proportion to the amount of habitat lost. Ferris (1979) claimed that a highway corridor passing through forest in Maine, USA, supported only half the number of breeding birds that the forest it replaced had once supported.

EXTENSION OF THE EDGE EFFECTS INTO NATURAL AREAS

Edge Effects

Distinct communities and habitats occur naturally with intergradation of different environments, often called ecotones. The edge is a human artifact where two contrasting habitats suddenly converge without the natural gradations. The human-made edge is usually inimical to most wildlife, and species from the natural interior do not inhabit edges. Species with excellent dispersal abilities, capable of invading and colonizing disturbed habitats, are attracted to edges, and move into the core of natural habitats if a road or utility corridor carries the edge into a previously undisturbed area. The edge experiences a different wind and radiation effect, leading to a different microclimate. If habitats are fragmented too much, and the ratio of edge to interior favours edges, the habitat will no longer be suitable for the interior species we most need to conserve (Ranney *et al.* 1981). The core of areas important for conservation should ideally not be dissected with roads and utility corridors which create edge effects (see Fig. 1).

Edge Effects on Distributions of Wildlife along Roads and Utility Corridors

Edge effects are noticeable by differences in diversity, density and distribution of wildlife populations along roads and utility corridors. The presence of species usually found only at the edge of habitats is noticeable. When the colonizers occur with the species already present the number of species is greater than in the original habitat prior to the road. However, some fauna avoid the edges. A few widespread species can dominate the numbers in edges. These patterns have been described for small mammals along powerline corridors in forests in the USA (Johnson *et al.* 1979) and birds (Anderson *et al.* 1977; Kroodsma 1982a and b; Kroodsma 1987), and studies have indicated that the structural differences of the plants which are regularly trimmed adds to the differences in faunal populations. Anderson *et al.* (1977) found that narrow corridors (12 m) showed less edge effect than the wide corridors (30.5 m upwards). A study of a powerline corridor in forest in the ACT described the same patterns of edge effect on populations of birds (Bell 1980).

Use of a highway right-of-way and median strip by small mammals in the USA showed distributions typical of edge (Adams and Geis 1983; Adams 1984), attracting grassland species and species that are less habitat-specific. A comparison of nesting birds on an interstate highway through forest in Maine revealed edge species in the corridor (Ferris 1979).

Risks to Wildlife from Edge Effects

Edges have been described as "ecological traps" since studies have shown that birds may be attracted towards the vegetation on edges to breed, only to lose their offspring through nest predation (Yahner *et al.* 1989). Harris (1988) and Yahner (1988) warn that edges can have negative consequences for wildlife, especially those species dependent on large undisturbed areas. It is difficult to delineate the edge dimensions and to quantify the effect of the edge, but edge effects may be more a function of length than width, and the structural variation at the edge can act as a barrier to dispersal of some species (Yahner 1988). Studies in the Amazon forest fragments (Lovejoy *et al.* 1986) show an avoidance of edges by interior forest birds noticeable more than 50 m into the forest, and the invasion of edge species of butterflies 200-300 m into the forest. In assessing the risk of extinction associated with fragmentation, edge effects must be considered (Wilcox and Murphy 1985).

THE BARRIER EFFECT

Physical Barriers

Fences are often erected to keep wildlife away from areas regardless of the mortality they may cause in such circumstances as drought and fire. The fence erected to prevent foot and mouth disease spreading south into South Africa has led to the death of hundreds of thousands of wildebeest *Connochaetes taurinus* migrating north towards water. In 1983 alone mortality was estimated at over 50 000. Numbers south of the fence are declining and are expected to continue to decline (Williamson *et al.* 1988; Williamson and Mbano 1988). In Western Australia the Agricultural Protection Board maintains 1 000 km of fence to stop emus *Dromaius novaehollandiae* from entering agricultural land, but it cuts across an area needed for seasonal migration. In 1976 over 10 000 died alongside the fence from starvation (Breckwoldt 1983; p. 248).

Many corridors are protected with fences. To prevent bird strike of the train the proposed VFT will have fences approximately 2 m high erected each side of the 200 m corridor (which would be 850 km long if the preferred Gippsland route was taken). The impact on birds striking the fence, and particularly other wildlife needing to move across the barrier fence could severely threaten some species, according to a report by CSIRO for the VFT Consortium (Casimir 1990; Rutherford 1990a and b).

Taylor and Martin (1987) listed the detrimental effects of fences on wildlife including entanglement, the cutting off of important natural factors such as water supplies, prevention of movement into suitable habitat areas,



A 3 m wide fire-trail with infrequent traffic can be a barrier to small mammals. (Dural, NSW)

Photo: Hamish Cumming

disruption of seasonal movement, overpopulation through limitations on dispersal and increased human access through use of fence maintenance roads.

The siting of a physical barrier should consider wildlife movements. A 46 km irrigation supply canal impedes wildlife movement to and from the Tana River in Kenya. The canal runs parallel to the river and limits access in dry periods to the river and the forage on the banks. Four underpasses for wildlife have been made, but no monitoring of use has been undertaken (Ledec 1987).

Roads, Utility Corridors and Edges as Barriers

A barrier need not be an impenetrable structure. There is nothing to prevent fauna crossing most roads, especially minor dirt roads which are also less used by vehicles. However, there is evidence that edges act as barriers (Yahner 1988), and a number of studies support the Canadian study by Oxley *et al.* (1974), who found that total clearance of 30 m or more was the main factor inhibiting the movement of small mammals across roads. Desert rodents, used to clearance, avoided crossing a 4-lane highway in the USA, although they lived alongside it in the vegetation encouraged by run-off from the road surface (Garland and Bradley 1984).

Road studies have examined roads of different widths, surfaces and traffic volumes (Oxley *et al.* 1974; Garland and Bradley 1984; Swihart and Slade 1984; Mader 1984; Bakowski and Kozakiewicz 1988; Baur and Baur 1990). Even a road in Kansas which was less than 3 m wide consisting of two dirt strips worn by the tyres of 10-20 vehicles a day, with vegetation on it, strongly inhibited crossing by prairie voles *Microtus ochrogaster* and cotton rats *Sigmodon hispidus* (Swihart and Slade

1984). In Germany a five-year study comparing the crossing by forest mice *Apodemus flavicollis* of road widths from 3 m to 6 m found that they did not cross, and if translocated very few returned (Mader 1984). A Polish study found the same species of forest mouse did cross a 5 m gravel road and concluded that lower traffic intensity than the roads in the German study may have contributed to the result; however, the road was a barrier to the bank voles *Clethrionomys glareolus* (Bakowski and Kozakiewicz 1988). In south-east Australia the endangered mountain pygmy possum *Burramys parvus* had its population dynamics disturbed by a road, which prevented the dispersal of males after mating (Mansergh and Scotts 1989).

Studies examining the use of structural or landscape features have discovered a barrier effect of roads on some species. In northern New South Wales Barnett *et al.* (1978) discovered that the mosaic-tailed rat *Melomys cervinipes* would not cross an overgrown, unused fire-trail 3 m wide, and that few brown antechinus *Antechinus stuartii* and bush rats *Rattus fuscipes* were trapped on both sides of the 4.5 m and 3.25 m unsealed low-usage roads. Samways (1989) found roads were a total barrier for one species of flightless bush cricket *Platycleis fedtschenkoi* spp. *azami* in southern France, and acted as partial barriers for several other bush crickets which could fly. Beside roads there were large accumulations of bush crickets which, unable to disperse, behaved abnormally by modifying their song.

In the USA, mowed grass strips 10-15 m wide have acted as barriers to dispersal of small mammals (Joule and Cameron 1975; Cole 1978). Schreiber and Graves (1977) found that powerline corridors with young trees and shrubs (maintained by removal of woody vegetation every 3-5 years) acted as a barrier to two small forest

mammals, a mouse *Peromyscus leucopus* and a shrew *Blarina brevicauda*, even though other small mammals lived in the established understorey of the corridor.

Small mammals have been the subject of most road crossing studies. Invertebrate studies include a Swedish snail species *Arianta arbustorum*, of which only one individual crossed the 8 m paved road and four crossed the 3 m gravel and sand track successfully (Baur and Baur 1990). Mader (1984) investigated whether carabid beetles crossed roads of various sizes and traffic-flow and found only one individual carabid beetle of the widespread species *Abax ater* crossed the two-lane paved highway, while species with restricted distribution such as *Molops piceus* and *Abax ovalis* avoided the verges and all road-crossing. Even butterflies may not fly across roads, possibly due to the extreme microclimate (van der Zande *et al.* 1980).

Implications of Barriers to Wildlife Movement

A barrier to dispersal of species can disrupt social organization. It can lead to local extinctions if an area is affected by fire or drought, can reduce the immigration of species to areas which may need replenishment, and also limit gene-flow, with subsequent "bottle-neck" effects. "For species with poor dispersal or dispersal-related problems... fragmentation may prove more critical than area as a determinant of extinction probabilities" (Shaffer and Samson 1985).

Arboreal mammals are also at risk, particularly those which do not show a tendency towards moving across the ground, such as the tropical rainforest Herbert River ringtail possum *Pseudocheirus herbertensis* and Lemuroid ringtail possum *Hemibelideus lemuroides* (Pahl *et al.* 1988), and the endangered Leadbeater's possum *Gymnobelideus leadbeateri* in Victoria. Leadbeater's possum is restricted to 500 m² of highland forest, and present road-widening projects for forestry will widen 2 000 km of roads to 50 m, with clearance increasing the area to 75 m (Preuss 1989 and 1990). Preuss believes that these roads could further endanger this species.

In the south-east forests of New South Wales the controversial Wog Way Road involves a 50 m wide clearance in the National Estate listed Coolangubra Wilderness (Salmon 1989). The widths of the new forest roads mentioned above are almost as great as a four-lane highway with a median strip and gravel road shoulders, with total clearance of 69 m (Garland and Bradley 1984). The effect of forest roads this width on native fauna needs to be assessed.



A powerline corridor which has become a corridor of weeds dissecting native vegetation. (Dural, NSW)

Photo: Hamish Cuming

THE DISTURBANCE EFFECT

Avoidance of Roads

Observations have shown that roads disturb large mammals, even if the road is not a barrier. Faecal pellets were counted along different types of roads in Colorado and it was discovered that mule deer *Odocoileus hemionus* and elk *Cervus canadensis* avoid roads to a distance of 200 m, with avoidance greatest near heavily-travelled roads (Rost and Bailey 1979). Mountain lions *Felis concolor* select home areas with low road densities (van Dyke *et al.* 1986a), and avoid making homes in areas near improved dirt or paved roads, which they also cross less frequently (van Dyke *et al.* 1986b). Grizzly bears *Ursus arctos* use habitats within 100 m of roads less than expected, which is the equivalent to a habitat loss of 8.7%. Many of these roads are in riparian areas along valley bottoms, which are important feeding areas for the bears. Avoidance of roads is independent of traffic volume (McLellan and Shackleton 1988).

Activity budgets have been estimated for caribou *Rangifer tarandus* because they depend on short summer feeding times when they also breed, and in which the young must become fit enough to survive winter and migration. Insect harassment creates behaviour patterns involving less feeding and lying time, and more locomotion. Roads create the same behaviour disturbance, and cow-calf dominated groups react more to low levels of disturbance. A distance of 600 m was the disturbance zone for roads with traffic, and 300 m for a road without traffic (Murphy and Curatolo 1986). Caribou depend on specific calving areas and disturbance in these can eliminate part of their range. Linear developments can delay or deflect movements, and traffic is a stimulus for flight. Herds winter a distance of 1.6 km from the Trans-Canada highway (Kiell *et al.* 1986). In areas where caribou cross the Trans-Alaska pipeline and have a choice between buried or elevated pipeline they tend to prefer the buried pipeline areas (Carruthers and Jakimchuk 1987).

In the Netherlands a long-distance effect on birds was noted by van der Zande *et al.* (1980), with specific species keeping particular distances from the roads, and lapwings *Vanellus vanellus* and godwits *Limosa limosa* as far as 1.8-2.1 km away. The study did not investigate the mechanism of disturbance, whether mechanical, acoustical or visual, but calculated a disturbance intensity which was the total population density loss suffered over the disturbance distance. An area became "psychologically unacceptable" to neotropical migratory birds in the USA after the construction of a nearby highway (Whitcombe *et al.* 1981). Cabin John Island near Washington was part of a continuous riparian forest and had always supported a large population of breeding

birds. The nearby highway has not touched the island, yet edge species have increased and the rare interior species such as the neotropical migratory birds have declined.

Noise Disturbance

The noise disturbance of roads is noted in a few studies. Mountain goats showed fear responses to highway vehicle noise, and the shifting of gears by trucks negotiating hills caused goats to run from the road even when the truck was 1 km away and the goats were 400 m from the road (Singer 1978).

Laboratory tests were performed on three desert species, used to the silence of high dune areas. A sand lizard *Uma scoparia* and kangaroo rat *Dipodomys deserti* were exposed to less than 10 minutes of recorded dune buggy sounds played intermittently at lower intensity than normal. This induced hearing loss in both species which lasted for weeks, leading to inability to respond to the recordings of predator sounds. A spade-foot toad *Scaphiopus couchi* was made to emerge prematurely from its burrow by playing 30 minutes of taped motorcycle sounds. These responses to off-road vehicles could cause death in the desert (Brattstrom and Bondello 1983).

The VFT at full speed is expected to produce a scream similar to a jet at close quarters, intolerable to humans, and able to carry for at least 5 km. If the route goes through Gippsland it will be heard in the wilderness areas on both sides (Miller 1988). Fauna are more sensitive to sound than humans, and many depend on efficient hearing for survival. Noise impacts on Australian wildlife need investigation.

ROAD-KILLS

Loss of Wildlife on Roads

The most obvious effect of roads is the mortality caused by collisions with vehicles. The data from road-kills can be useful for establishing the distribution and population trends of wildlife (Case 1978; Bennett, in press). The numbers lost in Australia are considerable, approximately one bird every 13 km, and one mammal every 30 km (Vestjens 1973; Disney and Fullagar 1978). An estimation of annual rates of road-kills of reptiles and frogs on sealed roads passing through suitable habitats in Australia was made by Ehmann and Cogger (1985). The crude estimate of approximately 5.5 million was regarded as conservative, and represented only 0.14% of total estimated deaths. Frog mortality is heavy after rain (Vestjens 1973). Invertebrate mortality has not been studied. No calculation has been made of the number of injured animals which die away from roads. During

drought when migration towards water takes place, the road-kills are higher and a greater proportion of the population is lost (Coulson 1989). The Tasmanian drought led to road-deaths of so many native animals early this year that letters were being written to newspapers suggesting speed limits and road closures be implemented (G. Houghton, pers. comm.).

Several Australian studies have examined road-kills (Vestjens 1973; Disney and Fullagar 1978; Coulson 1982, 1985 and 1989; Brown *et al.* 1986; Osawa 1989), and reviews of literature searches have also been made (Broadbent and Cranwell 1979; Coulson 1985; Bennett, in press). Road-kills, taken in conjunction with fragmentation of habitat, could have a significant adverse impact on populations of larger mammals (Broadbent *et al.* 1981). Road-kills could even cause local extinctions, such as a wildlife refuge or National Park which is too small to sustain the highway losses relative to replacement rates of its wildlife populations (Pressey *et al.* 1981).

At Mission Beach the densest population of casuaries *Casuarus casuarinus* had lost 19 of 59 known birds in two years, mainly to road kills (Smith and Muller 1988). The total loss had increased to 25 early in 1990 (Roberts 1990). The warning roadsigns have not helped, and local residents are being asked not to feed the birds, which attracts them to roadsides.

Patterns of road-usage are responsible for some road-kills. Insects can be attracted to the shiny surface, birds alight to feed on insects or collect grit, and scavengers are attracted to other road-kills (Vestjens 1973). Juveniles are often killed, as well as low-flying birds or birds flying along creek vegetation which is crossed by a bridge (Brown *et al.* 1986). The highway verges in the USA in winter provide grazing which attracts deer to roads (Carbaugh *et al.* 1975; Puglisi *et al.* 1974). Coulson (1982) found that mature male wallabies and kangaroos were most common fatalities, and wondered what this disproportionate loss may mean to the social organization and genetics of local populations. Increased numbers of cars and greater speeds on Indian roads has led to many more birds killed (Dhinsa *et al.* 1988), and a Bulgarian study supports the view that the increase in speed is a factor (Nankinov and Todorov 1984). Osawa (1989) found increased traffic to be a factor in road deaths of swamp wallabies *Wallabia bicolor* during Christmas holidays on Stradbroke Island. Reilly and Green (1974) reported that deer mortality increased five-fold after a new interstate highway was constructed parallel to the old two-lane road in Michigan.

Attempts to keep migrating deer off American highways are only partially successful. Techniques include fences (Falk *et al.* 1978), one-way gates to allow deer

back off the highway (Reed *et al.* 1974), highway lighting to allow better visibility for motorists (Reed 1981), and roadsigns which are not successful even when lit and animated (Pojar *et al.* 1975). Australian roads often display warning signs when an area of road is frequently crossed by marsupials, although the speed of vehicles is not reduced by signs (Coulson 1982).

Bird Collisions with Powerlines

Powerlines fragment bird flight paths, leading to collisions of birds with the lines, resulting in injury and death. No Australian study documents the horrific injuries and mass mortalities documented in the USA. In the USA collisions with automobiles and powerlines were the most frequent cause of bird mortality (Stout and Cornell 1976).

An analysis of collision studies reveal patterns in mortality. Poor visibility, bad weather, mass migrations, dispersal of juveniles and the fragmentation by powerlines of the area flown between resting and feeding create the situations in which the greatest number of deaths occur in the USA (Anderson 1978; Malcolm 1982; Ruzs *et al.* 1986). A Venezuelan study showed the importance of placing powerlines away from areas where birds congregate to breed and feed (McNeil *et al.* 1985). The powerline cut the lagoon area off from the sea, and birds flying between the two areas collided with the lines, including the endangered brown pelican *Pelecanus occidentalis*.

The use of transmission towers by birds for perching or nesting in treeless areas is also a source of electrocution, and towers need to be designed so as to minimize this (Ledger and Annegarn 1981).

ACCESS TO UNDISTURBED AREAS

Invasive Weeds and Predators

Plants and feral animals are easily introduced into the core of an area along a road, partly because the edge effect favours species with generalized requirements. Roads provide easy travelling conditions for animals, and are used by hunters such as foxes *Vulpes vulpes* (Bennett 1990). Simberloff and Cox (1987) give examples of these detrimental effects of corridors connecting natural areas, including the spread of diseases. The spread of fungal spores by vehicles, particularly *Phytophthora cinnamomi*, is responsible for die-back in some Australian forests (Bennett, in press). Arnold *et al.* (1987) found narrow roadside verges in Western Australia were mainly colonized by weeds and feral mammals.

Human Access

Roads also allow easy access to humans and the most frequently voiced concern about roads is this access. Deliberate illegal lighting of multiple fires in the Royal National Park in New South Wales in 1988 took place along roads and fire-trails. Pollutants are emitted by vehicles, including oil residues and heavy metals such as lead, zinc, copper, nickel and chromium (Broadbent and Cranwell 1979). Alongside heavily used roads the pollutants have potential biological significance if plants in which they concentrate form a large proportion of the diet of fauna, or if fauna living there breathe airborne pollutants. Pesticides and herbicides may be sprayed along roadsides and other utility corridors. Litter can cause death if ingested or if it traps fauna. Discarded bottles trap so many small mammals that they have been used as a data source in faunal studies in the USA (Pagels and French 1987).

Apart from the deaths caused by road-kills, deliberate hunting also takes place. In the USA, wild turkeys *Meleagris gallopavo* do not thrive in areas with road densities which exceed 6 km/1 000 ha, and proximity to roads is a factor in increased hunting mortality in season and illegal shooting out of season (Holbrook and Vaughan 1985). Roads also increase the legal and illegal hunting of grizzly bears *Ursus arctos*, which is the major source of adult mortality (McLellan and Shackleton 1988). Although wolves *Canis lupus* are now protected in the USA, illegal hunting means that they cannot establish a breeding population in areas in which the road density is greater than 0.59 km/km² (Thiel 1985).

The cassowary *Cassuarius cassuarius* population in Queensland is not only threatened by road-kills but is being illegally hunted with the heads as trophy (Roberts 1990). Cassowaries do not appear to occupy large territories, and are therefore vulnerable to roads in their habitat. Cassowaries are the only species capable of eating larger rainforest seeds, and are vital for the dispersal of 78 plant species (Stocker and Irvine 1983; Jones and Crome 1990).

Roads become part of a "foot in the door" principle, with developments sprawling alongside. They serve to open areas up to human expansion. This is especially noticeable in developing countries and undeveloped regions.

ATTEMPTS TO HELP FAUNA ACROSS ROADS

Bridges across rivers and gullies can be made into natural crossings if the bridge allows space alongside the banks, and particularly if natural vegetation is left as cover (Ratcliffe 1983; Pressey *et al.* 1981). Canopy

bridges have been recommended for arboreal mammals (Scott 1988) although none has been documented, with the exception of bamboo poles connecting orchard trees in China, to facilitate the movement of a predatory citrus ant (Huang and Yang 1987). Road construction often involves deep cuttings, and a tunnel for the road would allow an overpass for wildlife, providing a more natural crossing than an underpass.

Attempts to assist animals across roads are only made if their migratory needs are known. In England, school-children are involved with projects to help carry migrating toads across roads in the spawning season, the event is publicized and toad warning signs are temporarily erected on roads to encourage drivers to participate in the "Help a toad across the road" campaign (Anon. 1985). Badgers follow ancestral routes and can be directed to underpasses with fences (Ratcliffe 1983), and sections of electrified railway line have had special gaps cut in the conductor rail to allow the animals to cross without electrocution (Anon. 1986). The badgers utilize the railway line to cross a busy road.



Habitat left alongside creeks under bridges can provide safe road underpasses for wildlife. The left side has no protective vegetation. (Galston Gorge, NSW)

Photo: Hamish Cuming

Tunnels have had mixed success. A highway underpass for migrating deer in Colorado permitted 61% of surveyed deer to cross the highway safely, while 39% either did not cross or circumnavigated the fences which channelled deer towards it. It was considered too long (30.48 m) and too narrow and low (3.05 m) for deer to enter without fear. The tunnel was lit to compare use during times of darkness and light. Light seemed unnecessary, and skylights allowed traffic noise inside (Reed *et al.* 1975). The construction of culverts was recommended for the F3 freeway in New South Wales to prevent wildlife in parts of the Ku-ring-gai Chase National Park from becoming isolated from the rest

(Broadbent *et al.* 1981). It was recommended that the vegetation on the median strip be accessible, and light should penetrate the culvert to allow vegetation growth to minimize exposure to predators. These suggestions were not followed.

The New South Wales State Rail Authority constructed seven tunnels along a 35 km section of new railway line to allow movement of fauna. A survey of tunnel use was made (Hunt *et al.* 1987), and the problem raised that feral predatory mammals could focus their activities on tunnels which acted as funnels for prey. A comparison with the use of existing culverts showed small mammals used these more, as vegetation cover was well established, and they were too small to allow entrance of some predators.

The most successful tunnels are those constructed for the needs of specific species. Mountain goats *Oreamnos americanus* crossing a road to use a mineral lick in a Montana National Park were observed (Singer 1978). Two underpasses were constructed when the road was improved, and the goats were carefully considered during construction. Fences channelled them towards the underpasses. Crossing success was raised from 74% before the underpasses to 90% afterwards, although goats still reacted fearfully to traffic noise (Singer and Doherty 1985; Pedevillano and Wright 1987). In the Victorian Alps in Australia a "tunnel of love" was constructed to allow the male mountain pygmy possums *Burramys parvus* access in the breeding season to the females, which lived higher up the mountain, and which had been separated by a road. The tunnel was used immediately after construction, and has increased the winter survival rates of the females from 57% to 96%, because the dispersal of males after breeding was necessary to ensure enough food was left for the females. (Steer 1987; Mansergh and Scotts 1989). Basalt scree funnelled the possums towards the tunnel which was filled with the basalt boulders in which the possums live, and grills at the entrance prevented predator access.

CONCLUSIONS

There is a need for Australian studies to investigate the edge effect and disturbance zone for our fauna, and a need for studies on the widths and traffic intensities of roads which may become barriers to fauna. The remaining natural areas which may be fragmented by roads and utility corridors should be studied in terms of the viability of the areas left for the species which live there. If the dimensions are so small that the area becomes mainly edge we should seriously question whether the road should dissect it.

Ideally roads and other linear corridors should not be constructed through areas which are important to the

survival of species, or remaining wilderness areas. National Parks and conservation areas should also be protected from these structures, which are best sited on land already disturbed.

The clearance for new forest roads may be unnecessarily wide in areas of remnant old growth forest. The VFT concept involves a barrier to some wildlife which would be more severe than many existing linear barriers in Australia. Siting of such projects is significant, and all possible alternatives should be investigated if wildlife values and viable habitats are to be sustained for future generations. Once wildlife suffers the most serious effect of fragmentation it is far more costly to maintain unviable areas, and to breed species back from near-extinction, than it is to leave viable areas of habitat undisturbed while we have the choice.

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